

PASSIVE, PORTABLE VIBRATION ISOLATION
BY MEANS OF
PERMANENT MAGNETS AND HIGH TEMPERATURE SUPERCONDUCTORS

FINAL REPORT

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U.S. ARMY RESEARCH OFFICE

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13. ABSTRACT (Maximum 200 words) <p>We have built a prototype vibration isolation platform using permanent magnets that demonstrates that our concept of vibration isolation via decoupling is basically sound. Stabilized with elastomers, this vibration isolation device is capable of reducing mechanical vibrations reaching instrumentation attached to the platform by 50 db for frequencies above 5hz. Replacing elastomers with high temperature superconductors is expected to suppress the amplified response at the resonance frequencies around 1 to 2 hz of the present system, with tolerable degradation of the isolation for high frequency vibrations. With further improvement, it is possible to extend the range of frequencies that we can effectively isolate.</p>				
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STATEMENT OF THE PROBLEM STUDIED

We proposed to design, construct and evaluate a prototype passive portable vibration free platform using permanent magnets and high temperature superconductors. Our work plan consisted of three stages:

1. Design a magnet configuration for minimal coupling with a superconductor.
2. Construct the prototype.
3. Evaluate the performance of the prototype and redesign for improvement.

STATUS OF PROJECT AT BEGINNING OF REPORT PERIOD

At the end of the year 1994, we had constructed a prototype according to our first design and we reported a peak at 12 hz. in the transmissivity of vibrations from the support to the platform, which extrapolates to not so satisfactory a result for vibration isolation with this device. We interpreted this to be due to the instability induced by cross coupling between the translational and rotational degrees of freedom. To overcome this difficulty, we adopted a new design concept to utilize the magnetostatic force on single magnetic poles placed in a uniform magnetic field. This could be realized with a long magnet half inserted into a Halbach array, in a device that was shown schematically in fig. 4 in the last report. Our most urgent objective is to verify the validity of our new design approach. It was our goal to come up alternative designs in the six months of this reporting period, and to select one that is most promising for construction and evaluation.

SPECIFIC AIMS FOR THIS REPORT PERIOD

During this period, we have subdivided our task into two portions: one portion dealing with the force between the magnets, trying to arrive at a configuration with the least instability with the magnets, and the other portion dealing with the force between the magnets and the superconductors trying to attain minimal coupling with stability. So far, we have devoted our attention only to the first portion, for our previous experience tells us that it would be fruitful to attack the second portion only after we have achieved a more or less satisfactory result with the first portion. As an expedient towards the evaluation of magnetic configurations, we resorted to the use of elastomers as the stabilizing agent, temporarily forgoing a truly non-contact setup for the convenience of being able to operate and diagnose at room temperature. Our criterion is a low natural vibration frequency for the elastomer stabilized magnet configuration. Our aim is towards a resonance frequency below 1 Hz.

TECHNICAL APPROACH

We performed a systematic search for possible magnet configurations, taking into account the range of magnet sizes that are readily available on the market. We have given up some flexibility of the system, such as the capability to handle a range of weights, for the explicit simplicity of the magnet configuration design. As our first priority is verification of concept, a simpler design also has the advantage of less complication and ambiguity in the interpretation of results. This approach is also motivated by the desire to assess the supply of magnets in the general market can meet the rather stringent specifications that we know in advance we will need.

RESULTS AND DISCUSSION

We settled with a magnet configuration consisting of four pieces: a permanent magnet cylinder 0.5" diameter, 9.0" long; a hollow tube, 1.832" long, 1.010" inner diameter, 1.830" outer diameter; and two circular bands, 2.148" outer diameter, 0.498" wide and 0.149" thick. The two circular bands

are fitted symmetrically onto the outside of the hollow tube. The long cylinder magnet is attached to the platform which weighs 4.8 lbs and is supported across an air gap by the magnet assembly made up of the other three pieces. Fig. 1 is a schematic drawing of this magnetic configuration. Fig. 2 is a schematic drawing of the entire vibration isolation platform and its supporting structure.

In principle, the magnetic field in the active region of the above magnetic configuration is uniform to one part in a thousand, and should yield a resonant frequency of about 0.5 Hz. We actually measured the axial component of the magnetic field along the central axis of the magnetic assembly. The result is plotted in fig. 3, which shows us that we have a slight asymmetry between the two ends of the tube, giving rise to a non-uniformity in the magnetic field of one part in a hundred. We have not determined the exact origin of this asymmetry, which could be from error in the parts that hold the magnets in place, but not exactly at the intended positions symmetrically about the hollow tube, or from intrinsic deviations of the magnetization in the magnets from perfect uniformity, coming eventually from the manufacturing process used to fabricate these magnets. We estimated that this observed asymmetry of the magnetic field will raise the resonant frequency to about 1.5 Hz.

Nevertheless, we went ahead and measured the response of the system to external force excitation by coupling the magnet on the platform directly to an alternating current driven through a copper wire coil with an air core. The result is plotted in fig. 4, which shows a dominant peak at 1.1 Hz., possibly with a satellite at 1.3 Hz., and clearly separated from these, a weaker peak at 2.0 Hz. We have tentatively identified the dominant 1.1 Hz. peak to be due to translational oscillations mostly in the vertical direction, whereas the higher frequency 2.0 Hz. peak comes from vibrations that are mainly translational oscillations in the horizontal direction. Given additional stiffness from the elastomer, these frequencies are within our expectations. With the current magnet configuration stabilized by elastomers, we have a vibration isolation platform that does not require cryogenics, and can reduce background vibration amplitudes by a factor of 17 (equivalent to 25 db down in power) at frequencies above 5 Hz. [This is somewhat of an overestimation, as we are assuming negligible damping in extrapolating from the compliance to the transmissibility.] The supporting structures would have to be redesigned to incorporate high temperature superconductors in the next step. No more elastomers would be needed, and the supported structure would be truly levitated out of physical contact with any solid object. It is expected that the main effect of including the superconductors would be to dampen the response at the resonance frequencies, at the expense of a little more high frequency vibrations being transmitted.

PERSPECTIVE AND FUTURE DEVELOPMENT

However, before we forge ahead with incorporating superconductors, it is still desirable that the resonant frequencies exhibited by the basic magnetic configuration be even lower. We could improve in this direction by correcting for the end to end asymmetry in the magnetic field that we observed, either by reassembling the magnets to make sure that they are positioned symmetrically as designed, or by adding coils that would superpose a magnetic field with the opposite asymmetry to cancel the asymmetry of the present one, while maintaining the uniform average value. Ultimately, we want to procure a magnetic field that is uniform down to one part in a million. We know that magnetic fields of such a high uniformity is possible as they are currently being used in magnetic resonance imaging (MRI) instruments in medical applications. With such a highly uniform magnetic field, we will be able to build a magnetic configuration that will exhibit resonance frequencies in the 0.015 Hz. regime. Extrapolating from our current results, such a device would provide vibration isolation for frequencies above 0.05 Hz. at a level that is 25 db down in power (a factor of 17 in amplitude) from background.

At the current moment, the chief limitation of this prototype lies in practical concerns such as how uniform a magnetic field we can get. Ultimately, this approach is limited by the response of a freely suspended body (ie. all vibrational frequencies of rigid body modes vanish) to the background minute orientational variations of the environment. This response is infinite in the zero frequency limit, which translates in practice into the requirement of how long is it required for the vibration isolation to hold out on the platform.

SUMMARY OF THE MOST IMPORTANT RESULTS

Summarizing, we have built a prototype vibration isolation platform that has demonstrated that our concept of vibration isolation by decoupling is basically sound. With the present prototype, we can attach instrumentation weighing less than 2 lb. onto the platform, thereby shielding such instrumentation from background vibrations of frequencies above 5 hz., bringing the background noise at the equipment by a factor of 50 db down from that in the environment.

FIGURE CAPTIONS

- Fig. 1. A schematic drawing of the magnetic configuration used in the prototype vibration isolation platform.
- Fig. 2. A schematic drawing of the entire vibration isolation platform and its supporting structure.
- Fig. 3. A plot of the axial component of the magnetic field along the central axis of the magnetic assembly.
- Fig. 4. A plot the response of the system to external force excitation by coupling the magnet on the platform directly to an alternating current driven through a copper wire coil with an air core.

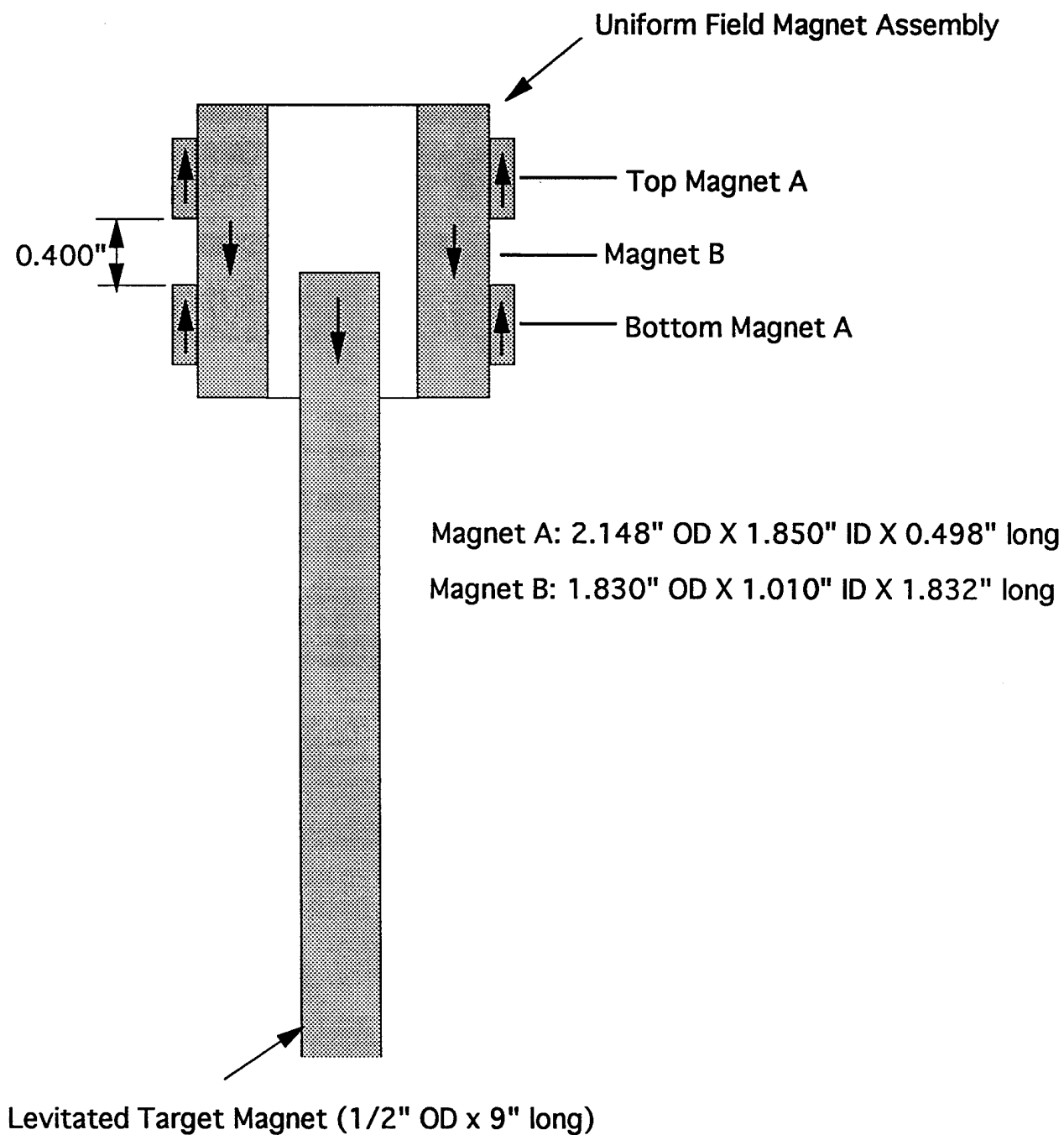


Figure 1

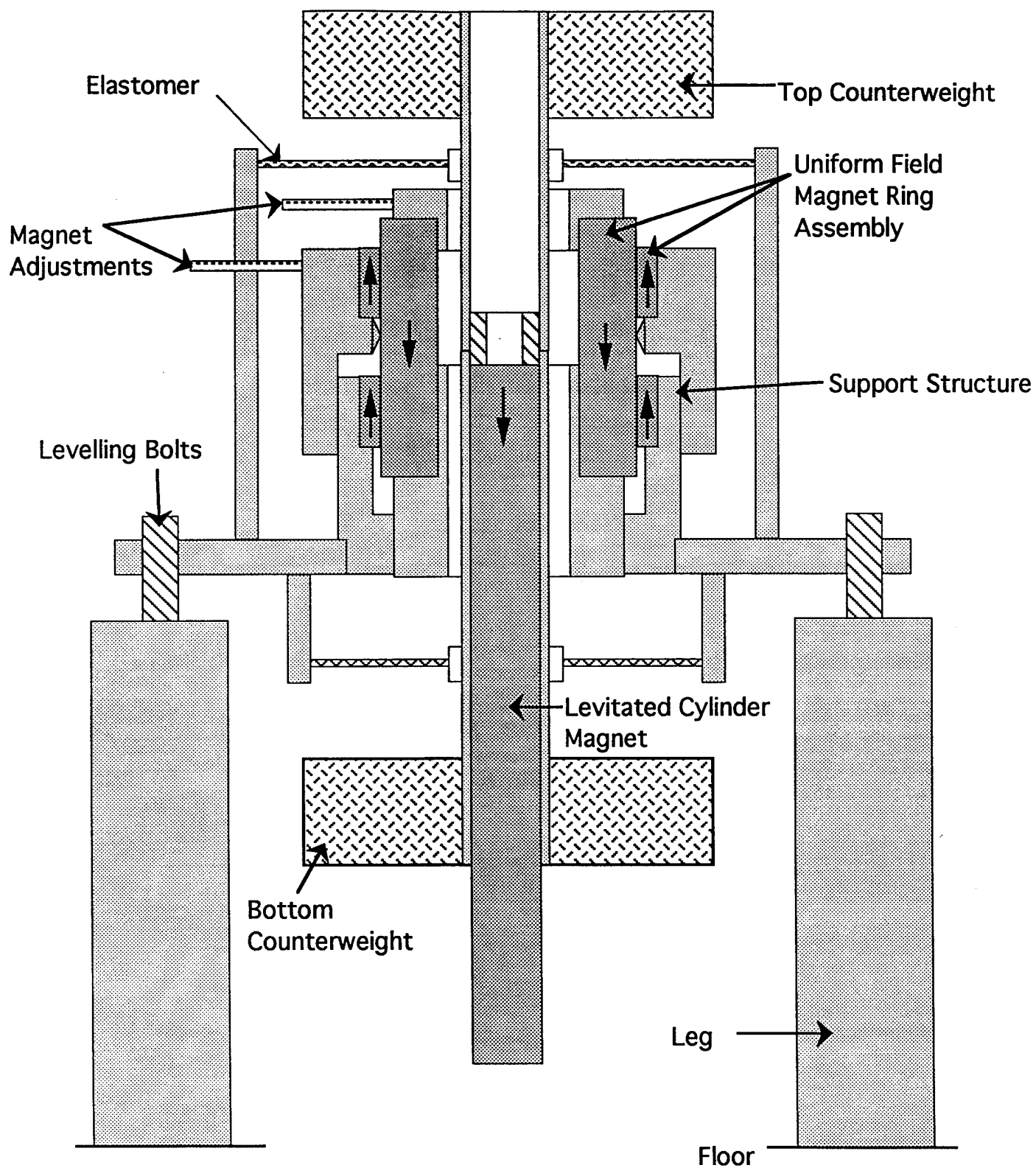


Figure 2

Axial Magnetic Field vs. Axial Displacement

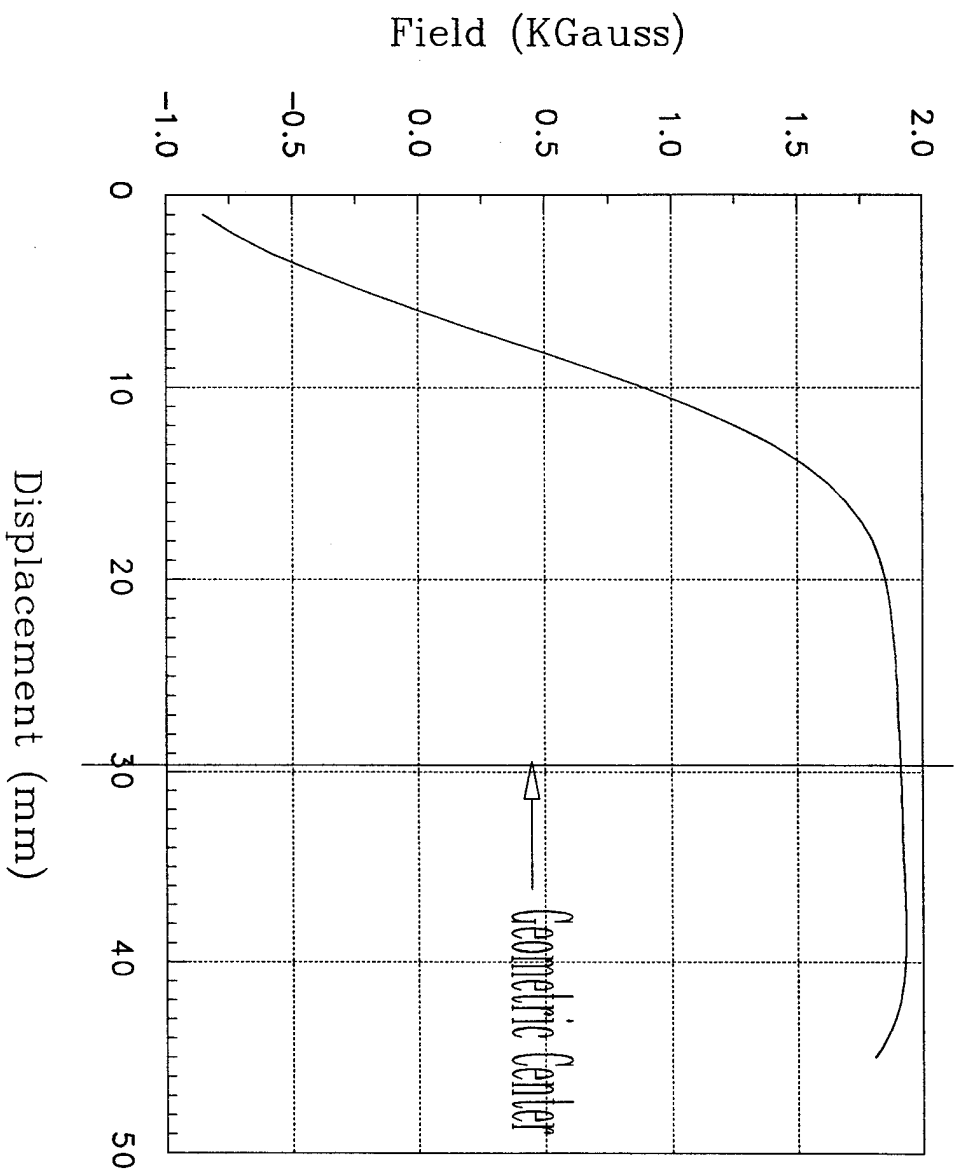


Figure 3

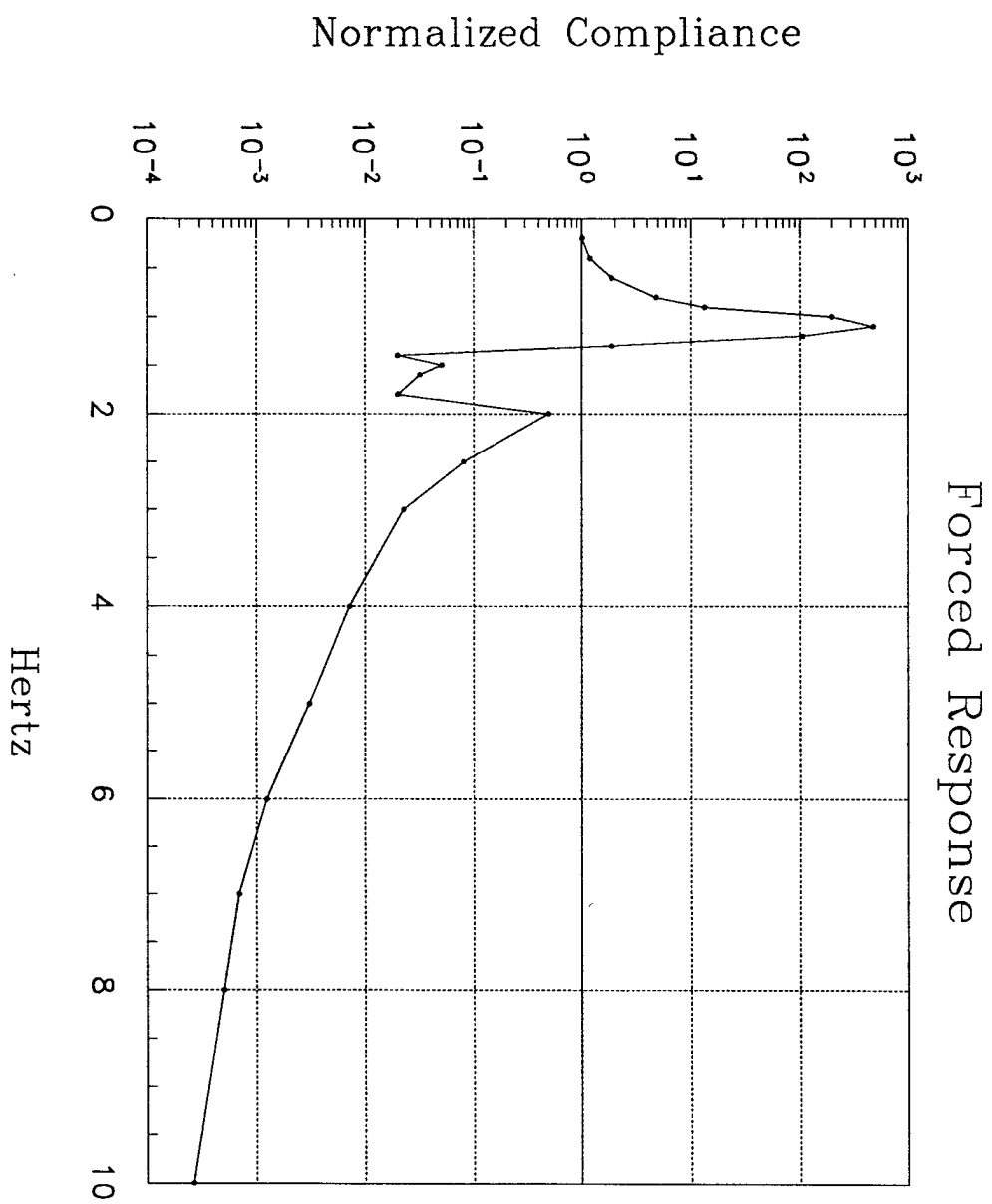


Figure 4

- **LIST OF ALL PUBLICATIONS AND TECHNICAL REPORT.**

We are about to submit a conference paper entitled, "Totally Decoupled Passive Magnetic Levitation," at the Third International Symposium on Magnetic Suspension Technology in Tallahassee, Florida on December 13 - 15, 1995.

- **LIST OF ALL PARTICIPATING SCIENTIFIC PERSONNEL SHOWING ANY ADVANCE DEGREES EARNED BY THEM WHILE EMPLOYED ON THE PROJECT.**

Dr. Wei-Kan Chu
Dr. Ki Bui Ma
Dr. Nanjui Zheng
Mr. Mark Lamb (graduate student)

No degrees earned by anyone while employed on this project.

- **REPORT OF INVENTIONS (BY TITLE ONLY)**

Invention disclosure entitled, "Applications of Totally Decoupled Passive Magnetic Levitation Systems," to be filed with the University of Houston.

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EDUCATION

Ph.D.	(Physics)	1969	Baylor University, Waco, Texas
M.S.	(Physics)	1965	Baylor University, Waco, Texas
B.S.	(Physics)	1962	Cheng-Kung University, Taiwan

EMPLOYMENT EXPERIENCE

1989-	Distinguished University Professor, Physics Dept., Univ. of Houston
1989-	Deputy Director, Texas Center for Superconductivity, Univ. of Houston
1981-1988	Research Professor of Physics, Univ. of North Carolina
1975-81	Staff, Advisory, and Senior Engineer at IBM
1972-75	Research Fellow, and Senior Research Fellow at CALTECH
1969-72	Postdoctoral Fellow at Baylor University

CREDITS/HONORS

- (1) 1995 International Workshop on Superconductivity, Material/Device Performance Award in recognition of superior performance in the category of Bearing Applications (June 21, 1995, Maui, Hawaii).
- (2) Superconductivity Award of Excellence for Outstanding Individual Accomplishment by the World Congress on Superconductivity (1994).
- (3) Fellow of the American Physical Society.
- (4) Distinguished Achievement Award from Baylor University, Waco, Texas (1991).
- (5) Senior U.S. Scientist Award from Alexander von Humboldt-Stiftung Foundation (1989).
- (6) Member of the following Review Panels:
 - NSF Review Panel for High Temperature Superconductivity (1992).
 - Review Panel Member for NSF SBIR division of Material Research (1992).
 - DOE Superconductivity Technology Program for Electric Power Systems (1993, 94).
 - DOE Panel on Superconductivity and Ceramic Materials (Chairman) (1992).
- (7) Gordon Research Conferences on Particle-Solid Interaction - Vice Chairman (1980), Chairman (July 1982).
- (8) Member Program Committee and/or International Advisory Committee: Ion Implantation (1976), Ion Beam Analysis (1977 and 1988 and 1995), Ion Beam Modification of Materials (1980 and 1988).
- (9) Conference Chairperson of the Materials Research Society's Spring 1986 Meeting, Palo Alto CA.
- (10) Member of Editorial Board for Nuclear Instruments and Methods (B) (1987 and 1988).
- (11) Author or co-author of 11 patents, and 14 technical disclosure publications related to materials processing.
- (12) Author of one book, and nine book chapters, editor of two books; author or co-author of 167 Journal publications plus 90 Conference Proceeding Papers or invited reviews.
- (13) Ten students obtained their Ph.D. under Prof. W. K. Chu's instruction and he currently has six students working toward their Ph.D. degree under his instruction.